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Data Acquisition for Solar Industrial Process Heat Field Tests

George Bush
Chuck Kutscher

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DATA ACQUISITION FOR SOLAR INDUSTRIAL PROCESS HEAT FIELD TESTS*

George Bush
Lawrence Livermore Laboratory
P.O. Box 808, L-46
Livermore, California 94550

Chuck Kutscher
Solar Energy Research Institute
1617 Cole Boulevard
Golden, Colorado 80401

ABSTRACT

Current solar industrial process heat field tests employ a variety of different types of data acquisition systems. In general, data acquisition has been unreliable for these projects and, as a result, only a limited amount of performance data has been available. This paper discusses the problems encountered with transducers and data acquisition hardware, the advantages and disadvantages of various types of data acquisition systems, and includes a recommendation as to which type is most suitable for monitoring industrial process heat field tests.

1. INDUSTRIAL PROCESS HEAT SOLAR SYSTEM PROJECTS

The Depatment of Energy (DoE) has an active program of experimental field tests to further the use of solar energy for industrial process heat. Over a dozen industrial process heat field tests are being funded currently [1]. Six of these have been in operation for over a year. Performance results for these projects are detailed in reference [2]. These six plus a seventh that is now operational, were visited during 1979 and are the subject of this report. Three of these systems supply hot water and four supply hot air. Table 1 is a summary description of the seven projects.

2. TRANSDUCERS

For each project the individual contractor has instrumented the solar system to monitor flow rates, temperature differences, and insolation. The industrial process heat program has drawn upon other solar programs in the selection of instruments. The National Solar Heating and Cooling Demonstration program, in particular, has conducted extensive research into transducer accuracy and reliability [3,4]. Their recommended transducer list is particularly appropriate for the low-temperature industrial process heat field tests. Thus, most of the field tests use the recommended sensors. For example, except at the L & P plant in Fresno, CA., which employs type T thermocouples, resistance temperature detectors (RTDs) are used exclusively for temperature measurements. In general, Ramapo target strain gauge meters measure liquid flow, and Eppley pyranometers measure insolation. Air flow is measured by a hot wire anemometer at Gold Kist in Decatur, Ala., and a pitot tube array at L & P in Fresno, Cal. Since some of the industrial process heat projects cover higher temperature ranges and include steam production, additional transducers will have to be selected and certified.

Two types of transducer problems were encountered: problems related to installation and problems of transducer failure. The rock bin storage unit at the L & P dehydration facility near Fresno was instrumented with multiple thermocouples and there was some breakage of lead wires during rock loading. At the lumber kiln facility at Canton Miss., gravel was inadvertently trapped in pipes during installation, and a pebble lodged against the target disc of the flowmeter causing erroneous readings.

Measurement of the direct component of insolation was incomplete or erroneous at various sites. The common method used to measure the direct beam component is to subtract the reading of a shadow band pyranometer from another pyranometer without a shadow band. At the Campbell Soup plant in Sacramento, Cal., the shadow band pyranometer is mounted on the tracking collector, and the diffuse component of the insolation is not measured when the collector is stowed. At several sites the shadow band was found to be out of adjustment.

The accurate measurement of small temperature differences is critical to the measurement of heat collected or of heat loss in subsystems. The data acquisition system at the soybean drying facility at Decatur measured a negative duct heat loss due to mismatching of the two RTD sensors located at each end of

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the duct which supplies solar heated air to the dryer.

The most trouble-prone transducer has been the flowmeter, with several sites reporting problems and failures. Target flowmeters were reported to open or short after periods of use, and turbine flowmeters would occasionally stick or bind and not rotate. Positive displacement gas meters had troubles with water condensation in the electrical rotational transducers mounted on them.

3. DATA ACQUISITION SYSTEMS

The data acquisition systems on the seven projects consist of six data loggers and one minicomputer-based system, as summarized in Table 2. The number of channels monitored at the various sites range from 12 at the Goldkist plant at Decatur, to 54 at L & P at Fresno, with all sensors typically scanned at 5-minute intervals. At those sites having the solar collector array located at considerable distances from the data acquisition system, remote signal conditioners are used, while the more compact sites do the signal conditioning at the data acquisition system.

The data loggers do not provide data in final form. They output data for further analysis off-line at a remote computer facility. Three sites use nine-track magnetic computer compatible tape that is changed monthly and shipped to a computer center for reduction and analysis. Two sites have digital cassette storage which collects three or four days worth of data. These sites also have telephone line connections so that the remote analysis centers can call in, read the cassette tape, rewind, and start recording again, all remotely. One site uses the strip printer on the data logger as the primary output. In this case the numbers are hand entered into the off-site computer for analysis. The site with the minicomputer delivers reduced data on-line and does not have any unreduced output except for diagnostic purposes.

A wide range of data acquisition system problems were observed. These included: effects of the immediate environment, faulty system integration, failure of the magnetic tape units, and power failures.

One of the worst environmental problems has been dust. At the Harrisburg, Penna., concrete block plant, the data acquisition system was originally installed in the block processing area and had to be relocated to the office because area and had to be relocated to the office of severe dust and dirt problems. Special enclosures and dust filtering were required at the fruit dehydration facility in Fresno and at the lumber kiln in Canton.

Another environmental problem had been water. The data acquisition system at the lumber kiln was damaged when the solar system stagnated. The pressure relief valve was undersized allowing pressure to build up. The CPVC pipe connecting the collector array and the storage tank ruptured showering the data acquisition system with hot water and steam.

Ambient temperature excursions have also caused problems. The data acquisition system at the Sacramento canning facility is located in a sunny stairwell. High ambient air temperatures damaged the nine-track magnetic tape recorder. This facility also has signal conditioners mounted in weatherproof boxes on the roof near the collectors. The temperature swings inside the boxes from night to day are so extreme that system calibration is affected.

System integration problems were apparent at some of the sites, causing delays in the start of data acquisition. At the Harrisburg concrete block plant the entire data logger had to be replaced with another brand because of incompatibilities with the nine-track magnetic tape recorder. There is still a minor interaction problem; when the strip printer is out of paper, the system stops writing data out to the magnetic tape.

The cassette tape recorders at the Fresno and Gilroy sites do not automatically reset after a power failure, and data is lost up to the time of the next remote interrogation. The nine-track magnetic tape recorders record an unreadable mark on the tape when the power fails, destroying the last record writtten. Depending on the tape format selected, this causes the loss of from five minutes to a day's worth of data. The data acquisition systems all have clocks, but some do not have a battery back up, and a power failure will cause the system to lose track of time.

4. DATA REDUCTION

The reduction of the digitized data to final outputs such as heat collected, heat delivered, and efficiencies, was done off-line at all installations except the lumber kiln. Some sites changed the magnetic tapes monthly and sent them in for analysis. Tape writing problems at these sites mean the loss of up to a month of data, as actually happened at one site. Also, considerable time may elapse before analysis. As of this writing the LaFrance, S.C., site has about half a year's unreduced data to be processed. Except for on-site visits and hand read data, both the solar heating system performance is unknown, and the health of both the solar and the data acquisition systems is also unknown. Sacramento site, where heat damaged the magnetic tape recorder, only a few days of hand-read data hve been reduced so far.

The installations with cassette tapes and telephone lines have worked better. The data from the Fresno site is read daily by phone from California Polytechnic University in San Luis Obispo, Cal., and reduced on an HP9825 desktop calculator. From the Gilroy site, data is read by phone from Annapolis, M.D., and reduced with a TI-95 hand calculator.

The minicomputer data acquisition system at the Canton lumber kiln has been plaqued with environmental problems, but when working, it delivers reduced data in real time. A system energy balance is calculated every day and allows the performance of the system to be easily monitored.

Data acquisition system accuracy is uncertain in many cases. At some sites there has been no calibration since installation, and at others critical instruments are inoperative or suspect. Along with problems of the quality of data, there are problems with the amount of data coming from some of the projects. Two sites have produced only a small amount of reduced data so far, and another one has been on-line only about half of the time.

5. REQUIREMENTS FOR AN IMPROVED DATA ACQUISITION SYSTEM

In view of the foregoing, there is little doubt that an improved data acquisition system is needed. Such a system must meet the needs of the data users, namely, the industrial owners, solar contractors, and those involved in solar research and design. It should be as uniform as possible to narrow the scope of potential problems, yet flexible enough to handle the various types of data produced by the entire spectrum of industrial process heat field tests.

The industrial owner needs to know to what extent a solar energy system can reduce his consumption of fossil fuel. A data acquisition system must tell him the amount of solar energy delivered to his process and the amount of fossil fuel saved. From this data, in conjunction with solar system cost information, he can determine the cost of the solar energy supplied. The solar contractor needs a data acquisition system to monitor the installed solar system in enough detail to verify its correct operation, to validate his solar design methodology, and to determine ways to increase system performance and reliability. Department of Energy project monitors and researchers need standardized information in order to assess the performance and reliability of various systems. The information should be presented in a way which facilitates cross-comparison between projects and allows for easy distribution of simplified information to those interested.

Data acquisition systems cover a spectrum in sophistication from scanners connected to digital voltmeters with visual readout, up to computer-controlled real-time acquisition and analysis systems at commensurate prices. The objective is to select the minimum system that fully meets the program requirements. Leaving out the non-recording display-only systems, there are three basic types of systems that can be considered:

(1) Data loggers that collect and store raw data on magnetic tape for mail or hand delivery to an off-site computer facility for reduction.

(2) Data loggers that send raw data over a telephone line to an off-site computer facility.

(3) An on-site minicomputer-based data acquisition system which outputs printed reduced data in real time at the site.

The first option is the least expensive approach, and is the most common system used presently in industrial process heat field tests. It has the disadvantages of potentially long delays between the time raw data is recorded and the time it is collected and reduced. This results in a time lag between the occurance of an operational problem and its discovery. In addition, data available on-site is fairly rudementary--usually individual channel readouts of temperatures, flow rates, and insolation.

The second option offers the potential for less delay in processing although it may still be subject to a central computer time schedule. Typically, in such a system, raw data is recorded continuously on a cassette tape and then played back over a telephone line to the remote computer center once per day. The data is processed when time permits. This option is especially attractive when a large number of sites are being monitored, as is the case with the Solar Heating and Cooling Demonstration Program. This option has the disadvantage of a costly and error-prone telephone link and does not provide reduced data on site in real time.

The third option eliminates the problems of the previous two. It provides for readable reduced data on-site in real time in a highly readable format. Both the industrial owner and any site visitors can see how the system is performing at any given time, and any operational problem can be quickly observed. The effects of changes made in the system are readily seen. For example, collector array efficiency can be read out before and after collector cleaning and compared. It also has the advantage of supplying reduced data long after the involvement of the solar contractor has terminated. This option has the disadvantage of increased cost and more equipment on site, which will require maintenance.

While the third option would have been too costly to consider a few short years ago, the recent large-scale integration of microcomputer circuits on silicon chips has changed the situation. Simple data loggers are now available which contain microprocessors programmed for analysis at a cost only slightly higher than previous models.

In March 1979, a set of Data Acquisition and Analysis Guidelines was prepared by the Solar Energy Research Institute and sent to all new industrial process heat field test contractors involved in the design phase of their projects [3]. The purpose of these guidelines was to eliminate some of the problems which had been inherent in the data acquisition systems of earlier projects. A key point in this document was the specification of an on-site data analysis system. At that time, the adoption of option three discussed above resulted in a cost increase over the typically used option one ($30,000 versus $12,000) but this was small compared to total design and construction costs of these projects ($500,000 to $1,000,000).

The guidelines were an attempt to prevent a repeat of specific problems encountered in operating projects. Other key points were:

- Final performance parameters to be determined to within 6% accuracy, based on an rms uncertanty analysis as described in NBSIR 76-1137 [4].
- Separation of the data acquisition and control systems.
- Calibration of all sensors at least once per year.
- Provision for a temperature and humidity controlled shelter for the data acquisition system.
- Use of IBM's "Instrumentation Installation Guidelines [5]," for sensor installation with certain added provisions, such as the use of a matched pair of RTDs for critical ΔT measurements.
- Specification of the reduced performance data to be reported to DoE on a monthly basis.

These guidelines are being used by current solar industrial process heat contractors in the design of their field tests. There are a variety of off-the-shelf hardware systems which satisfy these guidelines, and each contractor is free to choose the system that he prefers. We believe that the most reliable data acquisition for these projects will only come when a standard single hardware system is used for each field test. In this way, the number of different possible problems can be kept to a minimum, and one service contract can be drawn up to maintain all of the systems. One of the authors (Bush) is currently heading up an effort to select the best off-the-shelf system in accordance with the aforementioned requirements.

6. REFERENCES

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[5] "Instrumentation Installation Guide lines," SOLAR/001-77/15, IBM Corporation, November 1977, 101 pp, Available from NTIS.

Table 1. Description Summary

Project Location	Contractor	Process	Fluid	Temp. °C	Area m^2
Hot Water Projects					
Campbell Soup Company Scaramento, CA	Acurex Corp. Mountain View, CA	Can Washing	Water	65	682
Reigel Textile Corp. La France, SC	General Electric Co. Philadelphia, PA	Textile Dyeing	Water/ Glycol	132	621
York Building Products Harrisburg, PA	AAI Corp. Baltimore, MD	Concrete Curing	Water/ Glycol	57	857
Hot Air Projects					
Gold Kist, Inc. Decatur, AL	Teledyne-Brown Engr. Huntsville, AL	Soybean Drying	Air	60	1218
J.A. LaCour Kiln Services Canton, MS	Lockheed Huntsville, AL	Lumber Drying	Water	61	234
Lamanuzzi and Pantaleo Foods Fresno, CA	CA Polytechnic State U. San Luis Obispo, CA	Fruit Drying	Air	63	1950
Gilroy Foods, Inc. Gilroy, CA	Trident Engr. Assoc. Annapolis, MD	Onion Drying	Water	80	553

Table 2. Data Acquisition Systems

Project	On-Site Equipment	Reduction Procedure
Campbell Soup	Acurex Autodata Nine data logger, magnetic tape recorder, line printer	Magnetic tape pickeed up by contractor; reduced by computer at contractor's offices
Reigel Textile	Esterline-Angus PD2064 data logger, magnetic tape recorder	Magnetic tape mailed to contractor, reduced on PDP-11 at contractor's offices
York Building Products	Fluke 2240 B data logger, magnetic tape recorder	Magnetic tapes picked up by contractor and reduced by computer at contractor's offices
Gold Kist	Fluke 2240 B data logger	Printer tape picked up by contractor, data manually keypunched and reduced by computer at contractor's office
LA Cour Kiln Services	PDP-11/03 minicomputer disc drive, line printer	Data automatically reduced on site. Printout mailed to contractor's office
L & P Dehydration	Acurex Autodata Nine data logger, cassette recorder, modem	Data read once per day from cassette tape. Transmitted via commercial telephone line to contractor's office where it is reduced by a HP-9825 desktop calculator
Gilroy Foods	Acurex Autodata Nine data logger, cassette recorder, modem	Data read once per day from cassette tape. Transmitted via commercial telephone line to contractor's office where it is reduced by a TI-95 hand calculator.